National Aeronautics and Space Administration

# Human and Robotic Exploration Activities at Small Bodies: Opportunities for Science


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Stakeholder Engagement on the Global Exploration Roadmap: Focus on Science

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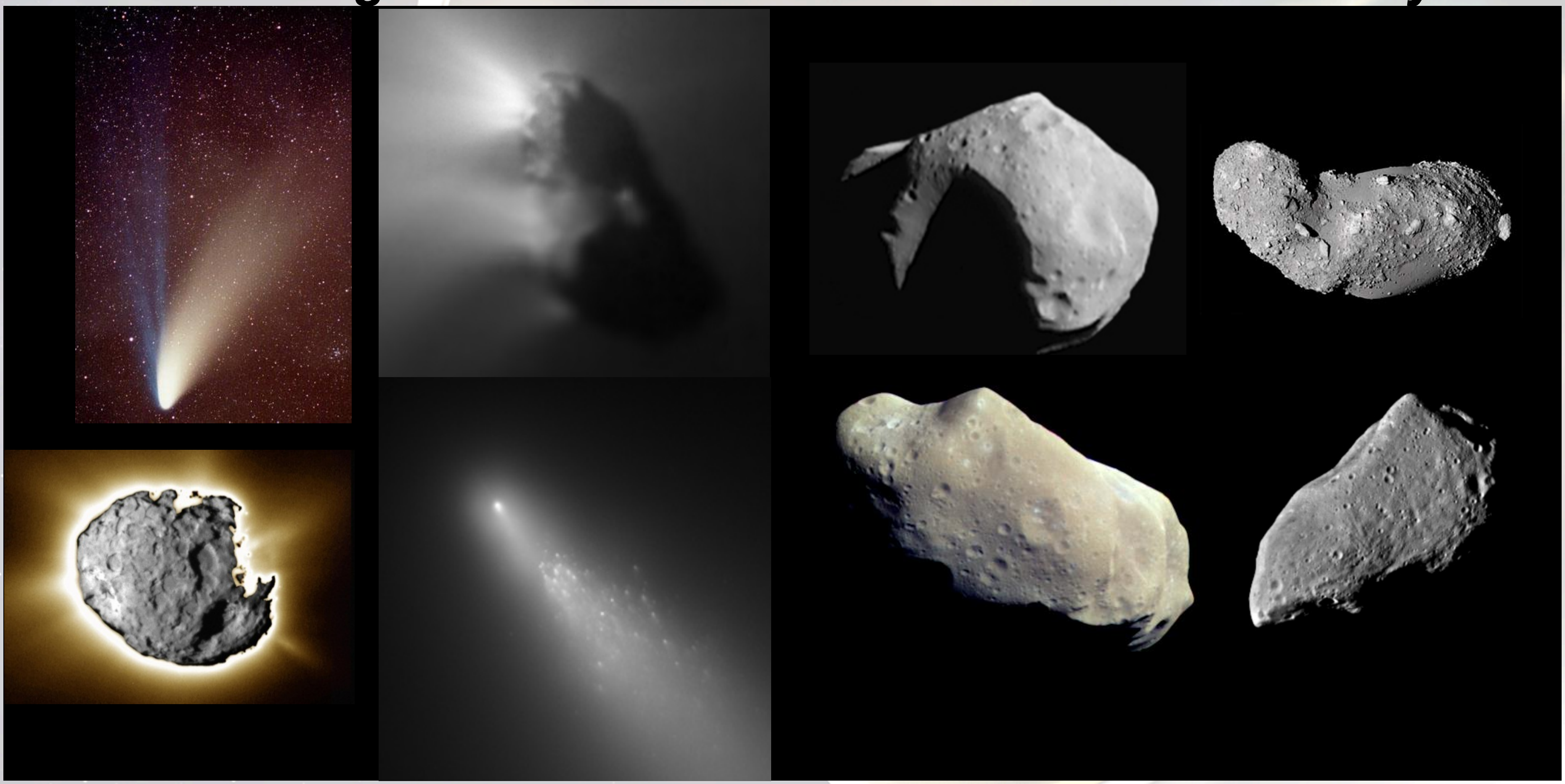
# Outline

- Introduction to Small Bodies
- Small Body Focal Areas
- Planetary Decadal Science Themes
- Role of Robotic Precursors
- Science Enabled by Human Presence
- Future Considerations

# Small Bodies = Comets and Asteroids

***Primordial fragments from the formation of our Solar System***

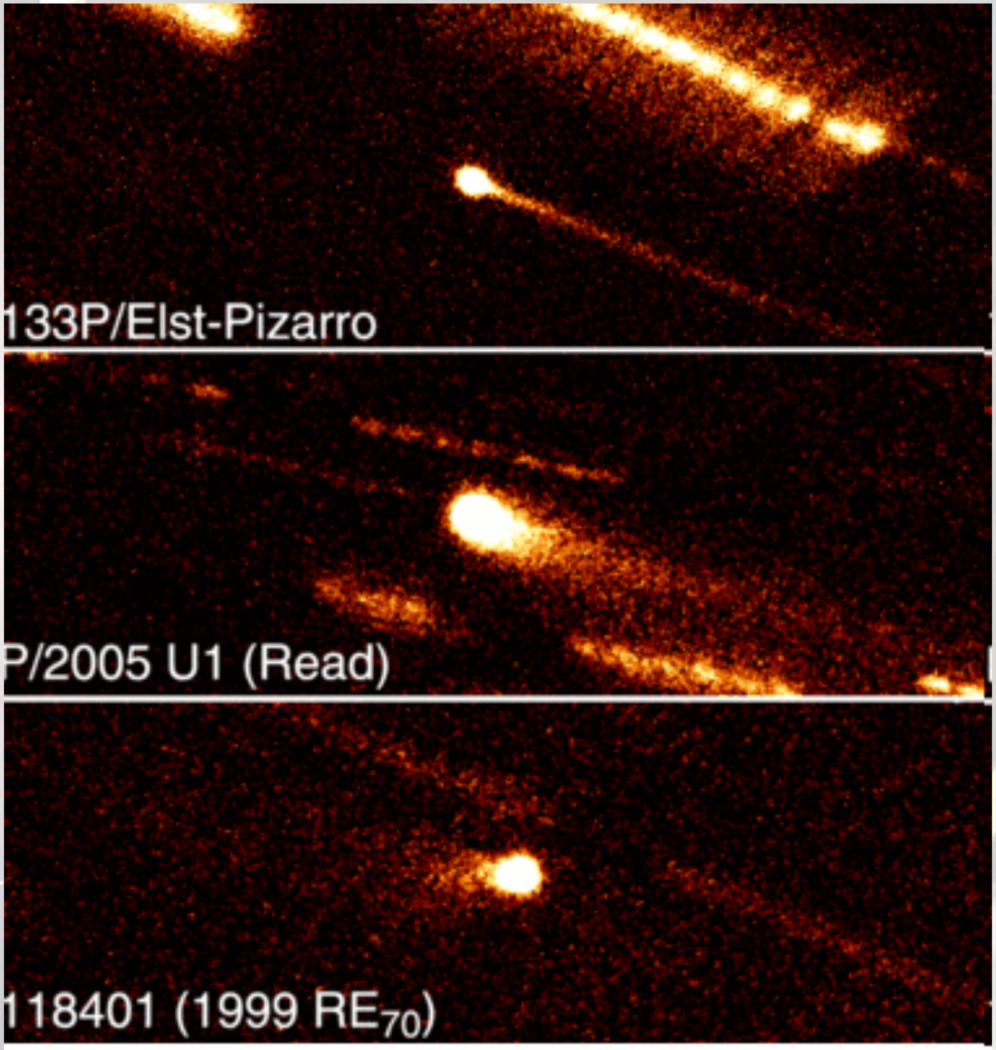


Comets contain volatiles in the form of ices and can produce visible atmospheres (coma)

Asteroids generally lack active ices and appear to be essentially inert

# Examples of Dormant Comet/Active Asteroids

- **Recent discoveries of main belt comets**
- **Small bodies are an extremely diverse population of objects**
- **Represent several avenues for scientific research**




(Images taken with the UH 2.2-meter telescope by H. Hsieh and D. Jewitt, University of Hawaii.)

# Detection of Water Vapour at Asteroid (1) Ceres

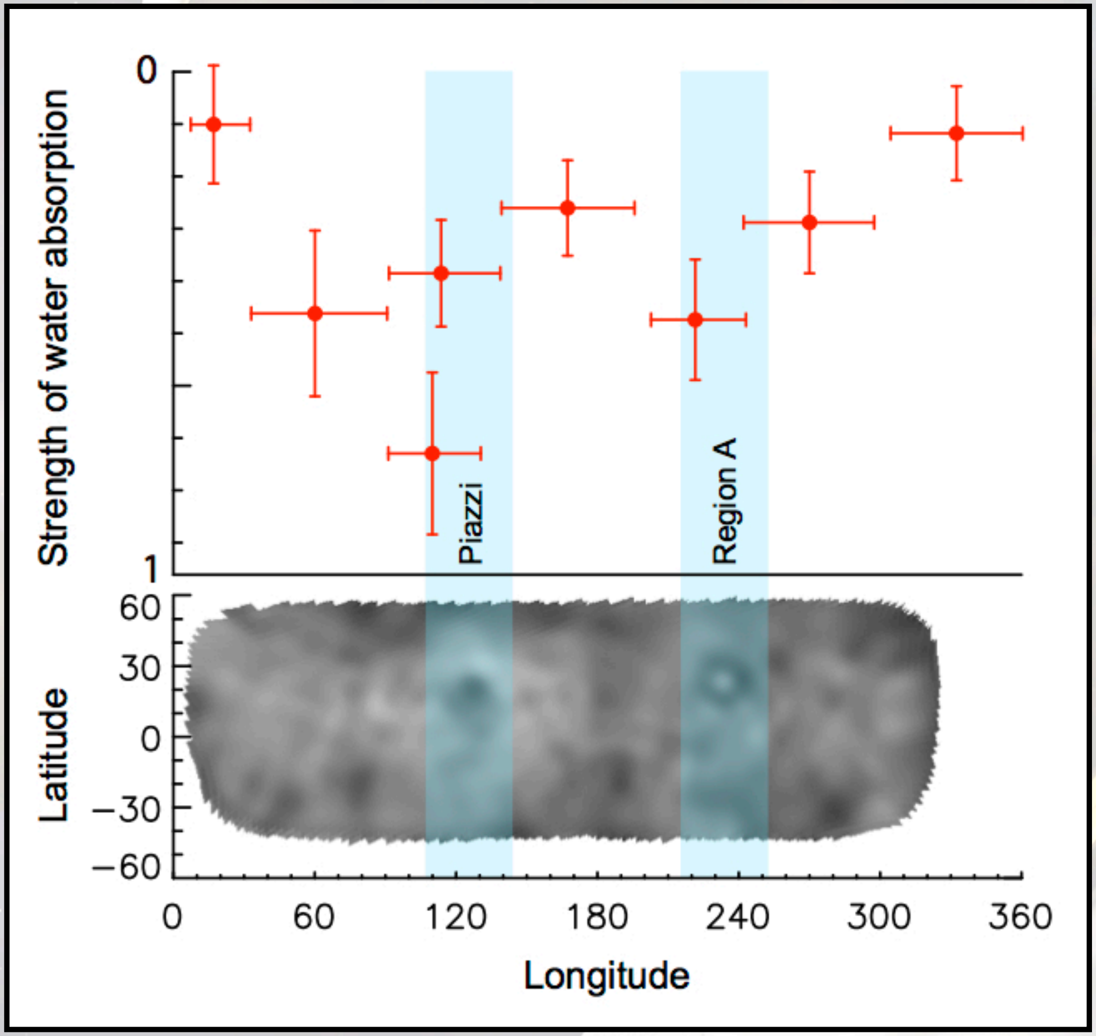



Image credit from Küppers et al., 2014

# Small Body Source Regions

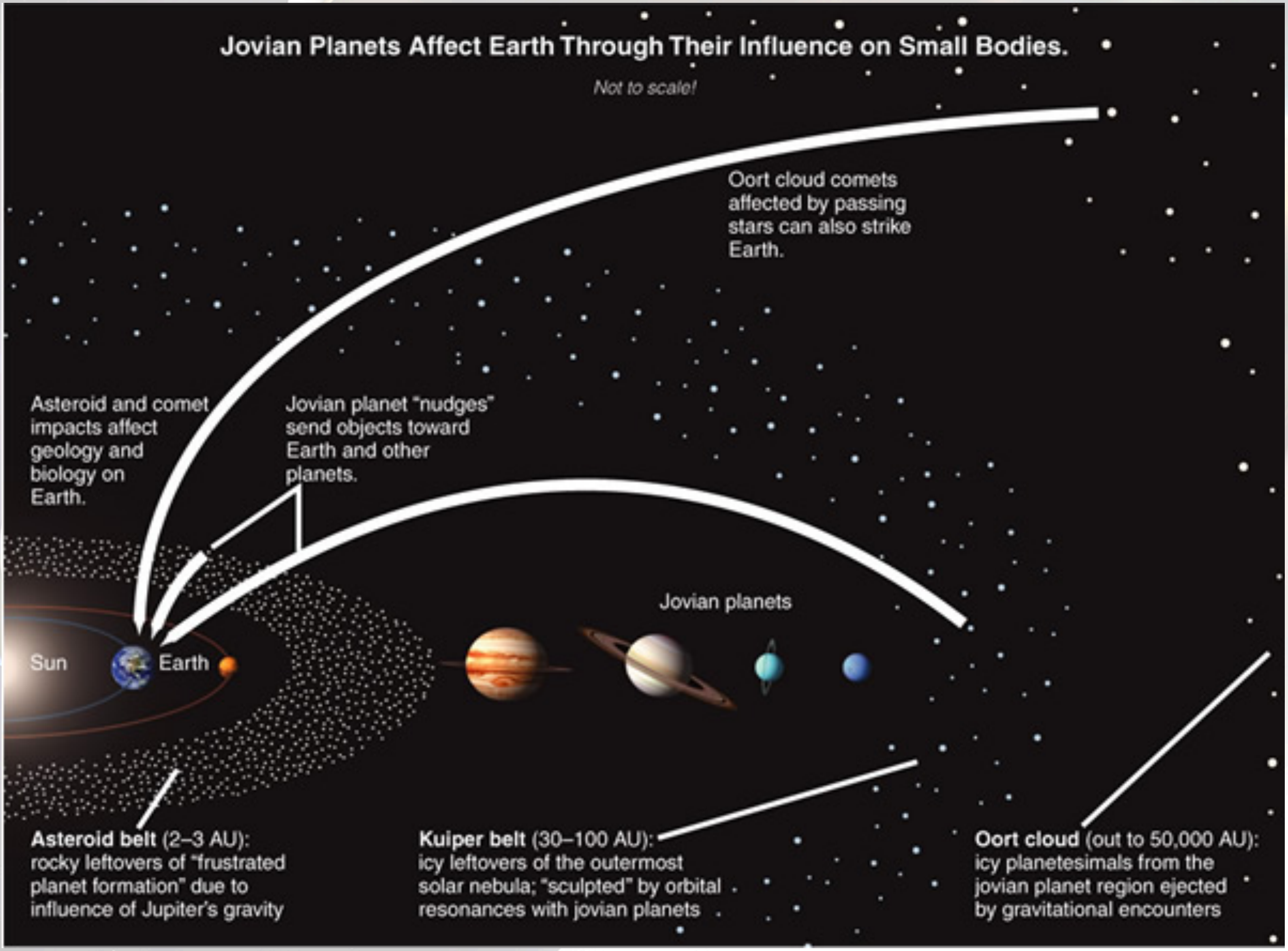
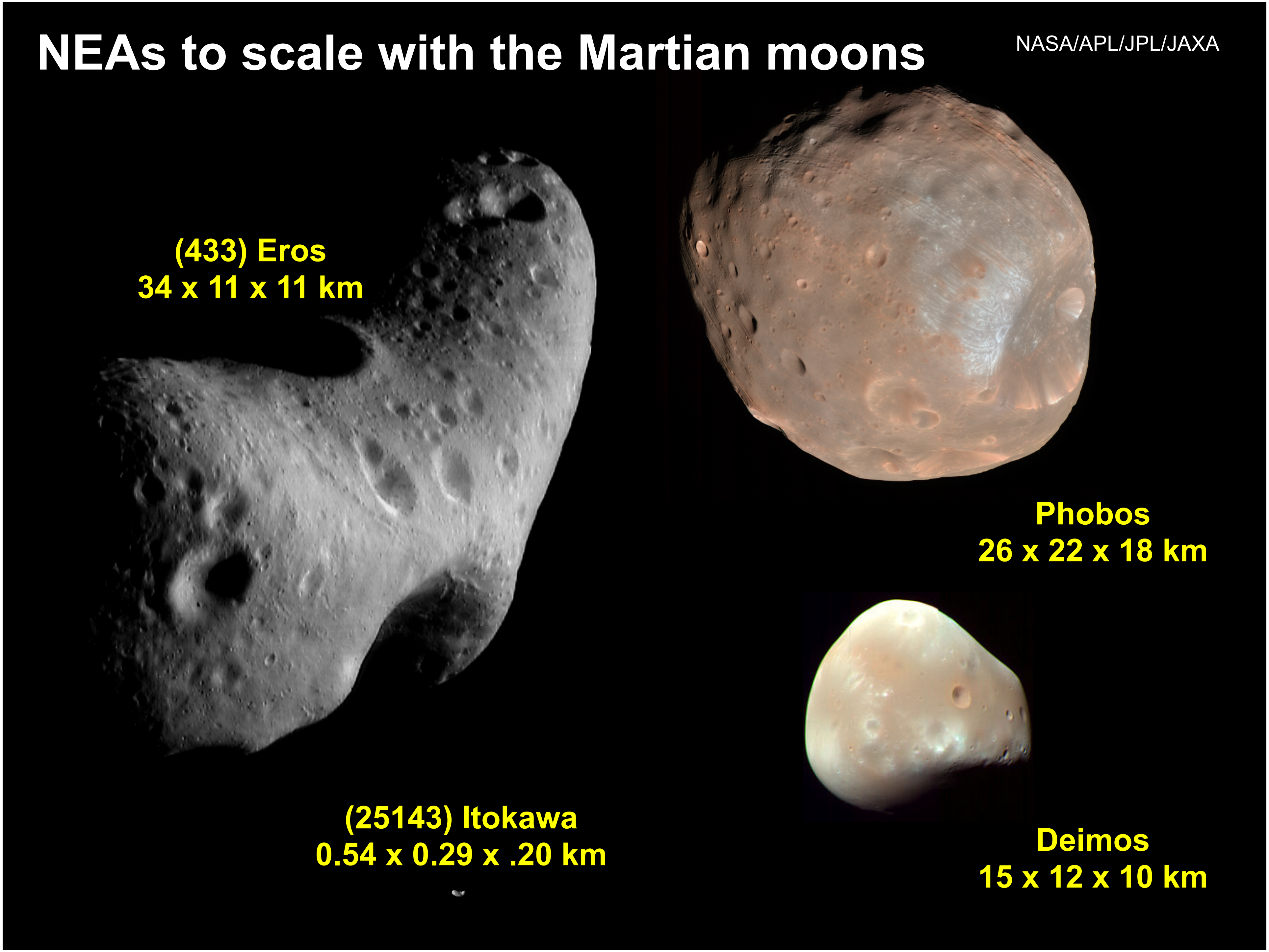


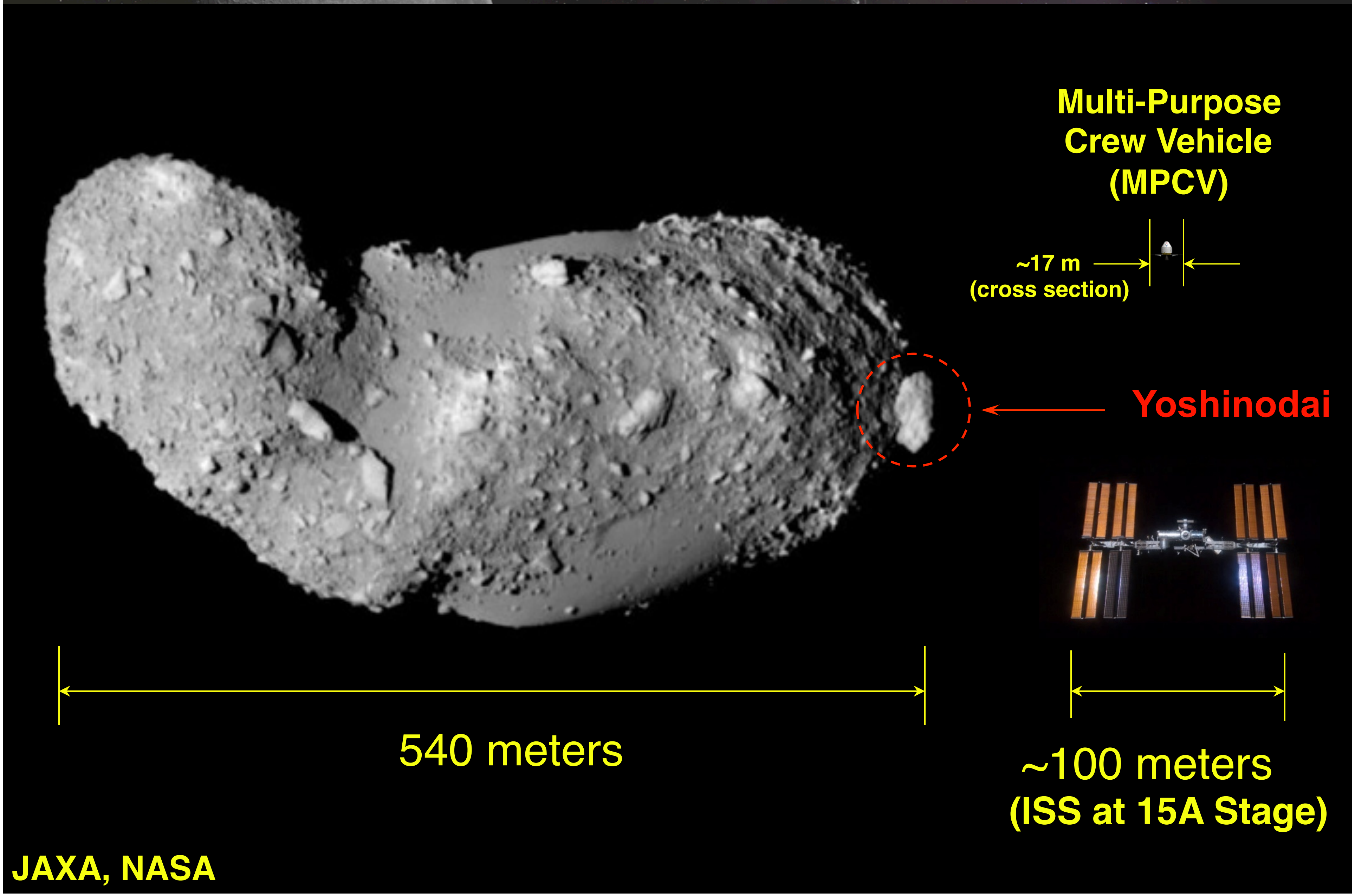

Image courtesy of Addison Wesley

# Potential Small Body Destinations

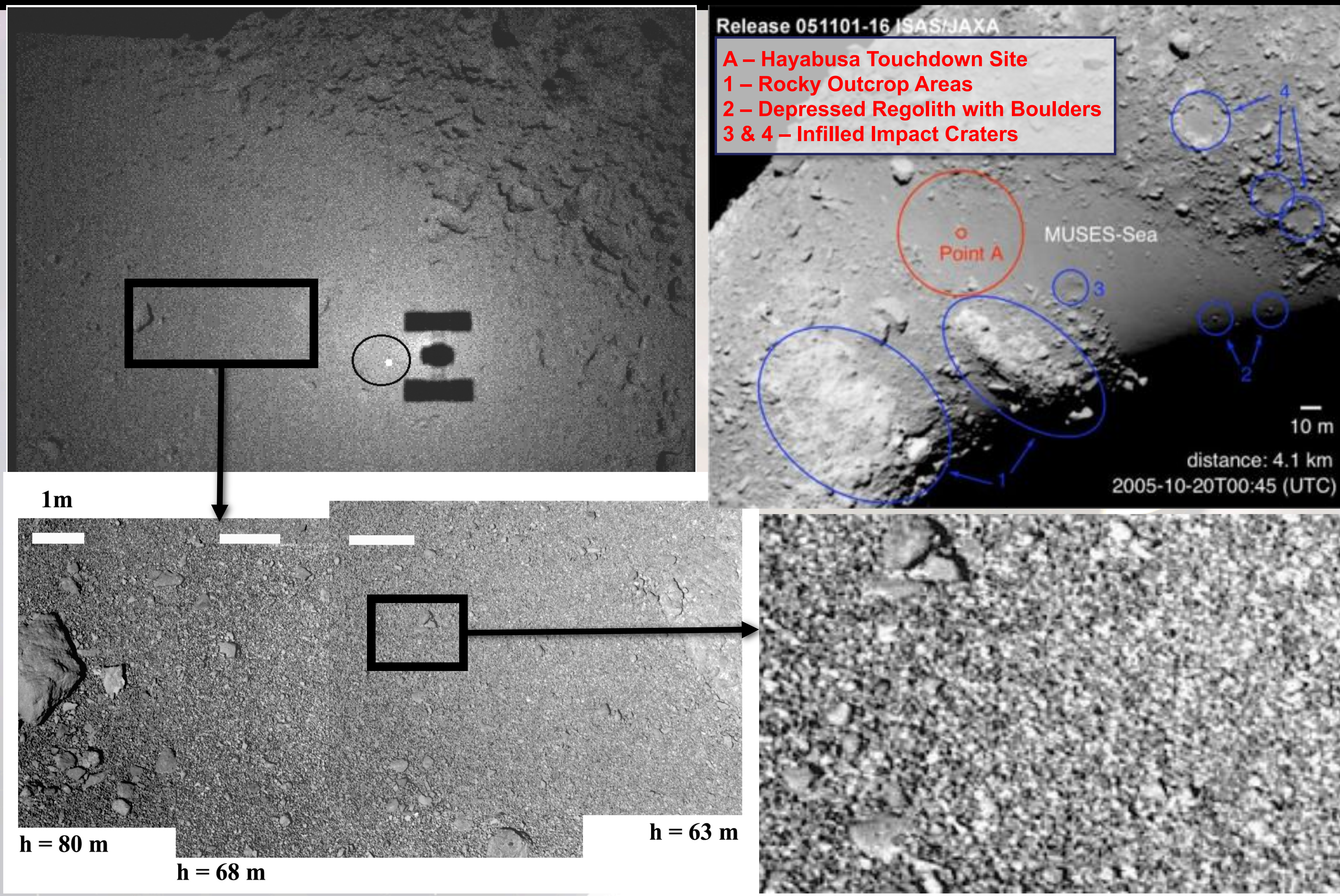
- **Near-Earth Objects (NEOs) and Phobos/Deimos are small airless bodies with "similar" physical characteristics**
- **However they represent distinct and separate destinations for robotic and human exploration**
  - NEOs - any small body passing within 1.3 Astronomical Units (AU) of the Sun
    - Note that 90 – 95% of the NEO population are Near-Earth Asteroids (NEAs)
    - 5 – 10% of NEOs may be extinct or dormant comets (i.e., no evidence of activity)
    - NEAs are the targets for Human Exploration
  - Phobos and Deimos are natural satellites of Mars at ~1.52 AU

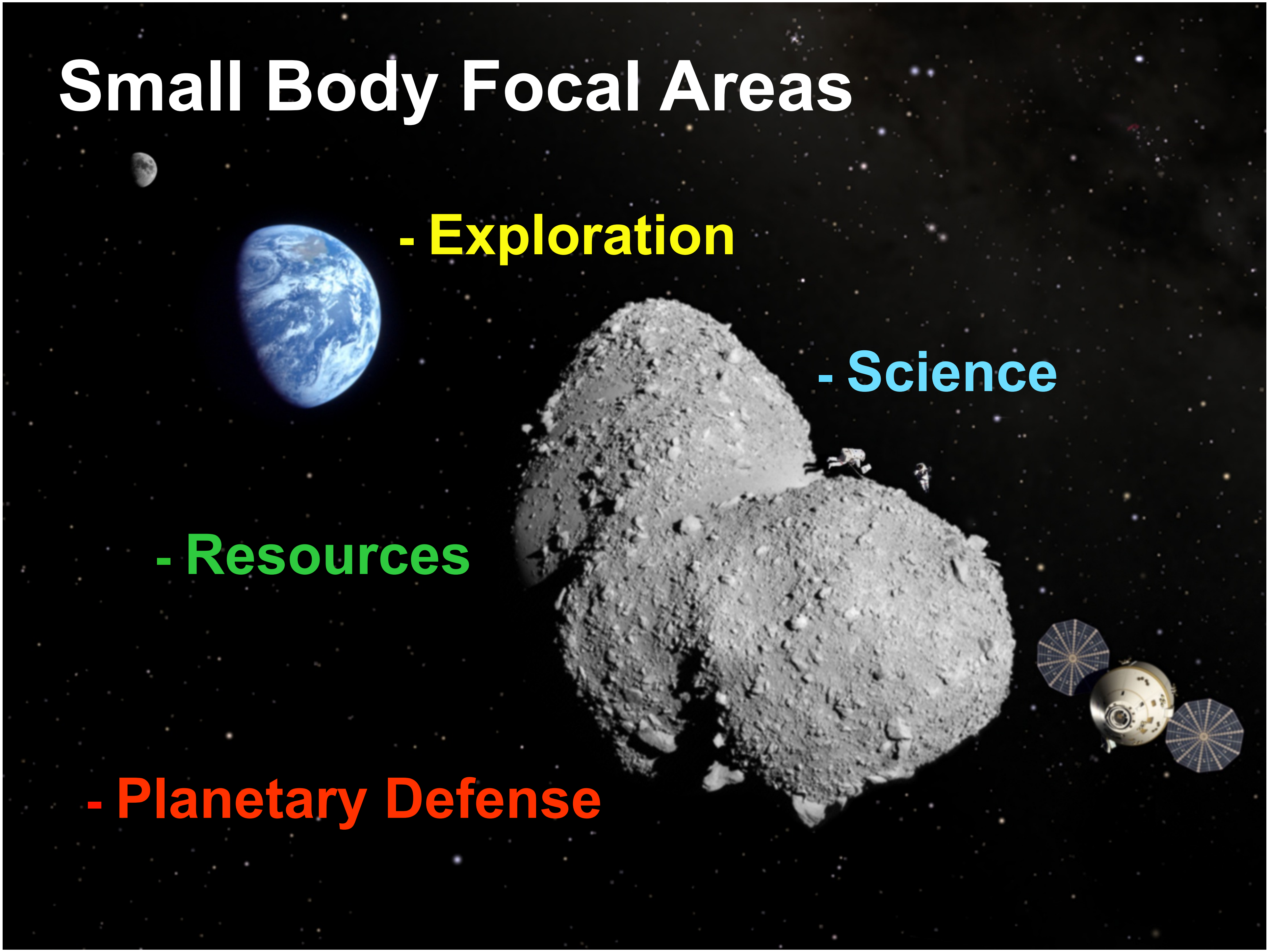

NEAs to scale with the Martian moons
NASA/APL/JPL/JAXA
(433) Eros
34 x 11 x 11 km
Phobos
26 x 22 x 18 km
Deimos
15 x 12 x 10 km
(25143) Itokawa
0.54 x 0.29 x .20 km

# Asteroid Itokawa, ISS, and the MPCV



# Hayabusa Touchdown Site at Itokawa




Small Body Focal Areas
- Exploration
- Science
- Resources
- Planetary Defense

# Overlap of Small Body Focal Areas

## Human Operations

Internal Structure (monolith vs. rubble pile)
Sub-surface properties
General mineral, chemical composition

## Science

Internal Structure (monolith vs. rubble pile)
Sub-surface properties
Detailed mineral, chemical, isotopic composition

## Intersection of all

Location (position prediction/orbit)
Size (existence of binary/ternary)
Rotation rate & pole orientation
Particulate environment/Debris field
Electrostatic charging & plasma field
Thermal environment
Gravitational field structure
Mass/Density estimates
Surface morphology and properties
Regolith mechanical & geotechnical properties

## Planetary Defense

Internal Structure (monolith vs. rubble pile)
Sub-surface properties (-> Beta)
General mineral, chemical composition

## Resource Utilization

Detailed mineral, chemical composition

# Planetary Decadal Science Themes

- **Building New Worlds -- understanding solar system beginnings**
  - What were the initial stages, conditions and processes of solar system formation and the nature of the interstellar matter that was incorporated?
  - What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?

- **Planetary Habitats -- searching for the requirements for life**
  - What were the primordial sources of organic matter, and where does organic synthesis continue today?

- **Workings of Solar Systems -- revealing planetary processes through time**
  - What solar system bodies endanger and what mechanisms shield Earth's biosphere?
  - How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?

# Small Body Science

- **Small bodies are the left over primitive materials from the earliest stages of Solar System formation**
  - NEAs sample a wide diversity of material types and reservoirs
  - Context of Small Body origins and evolution

- ***In situ* science enables a better understanding of these bodies' origin/dynamical history and early Solar System formation**

– Proximity science investigations ("orbit" or station keeping modes)

– Surface and sub-surface science investigations (regolith/material properties drivers) to identify origins, investigate impact history, understand space weathering effects, *etc*.

- **Sample return from these bodies informs the nature of the material composition, thermal, oxidation state, and collisional histories**
  - Identification and characterization of samples
  - Acquisition under low-gravity regimes with regolith and material property drivers
  - Storage and containment of samples (i.e., cold/frozen samples)

- **Identification of volatile and organic materials has major implications for astrobiology**

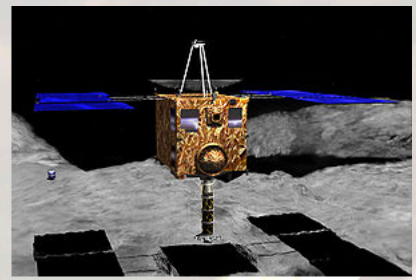
– Delivery of pre-biotic molecules and volatiles to Earth via NEAs (e.g., origin of Earth's $H_2O$)

# Small Body *In Situ* Characterization

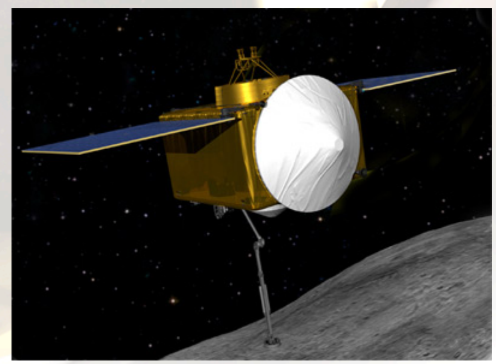
- **Prior to sending a piloted mission to a NEA, additional *in situ* characterization of the target is <u>required</u>**
  - Obtain basic reconnaissance to assess potential hazards that may pose a risk to both vehicle and crew (e.g*., Ranger, Lunar Orbiter, Surveyor, LRO* have done for the Moon*)*
  - Some NEAs may have physical characteristics that would make them unsuitable as targets for early human exploration
  - Fill in Strategic Knowledge Gaps (SKGs)
- **Precursor missions would also assess the NEA for future activities to be conducted by the crew and their assets to maximize mission efficiency**
  - Proximity operations (spacecraft, robotic assets, crew on EVA)
  - Surface activities (scientific and engineering investigations)
  - Touchdown site selection
  - Sample identification and collection

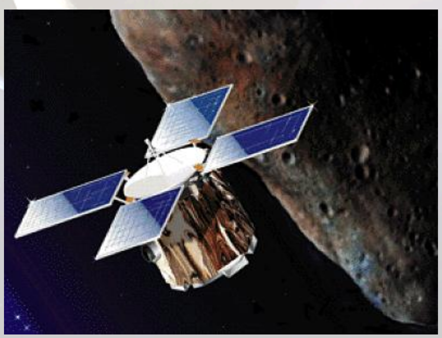
# Small Body *In Situ* Characterization

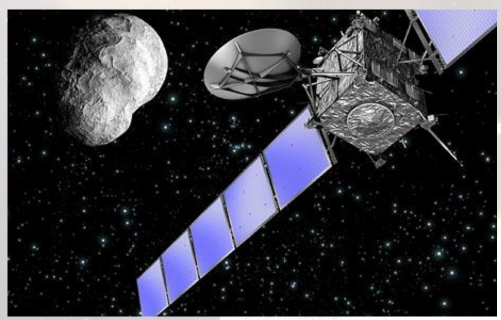
- **Build on lessons learned from other small body missions**
- **Strong overlap with Science, Exploration, Resource Utilization, and Planetary Defence**



- **Past, current, and future mission examples**
  - **NEAR Shoemaker, Hayabusa,**
  - **Rosetta, Hayabusa 2, OSIRIS REx,**
  - **AIDA, ISIS**







# Robotic Precursor Activities

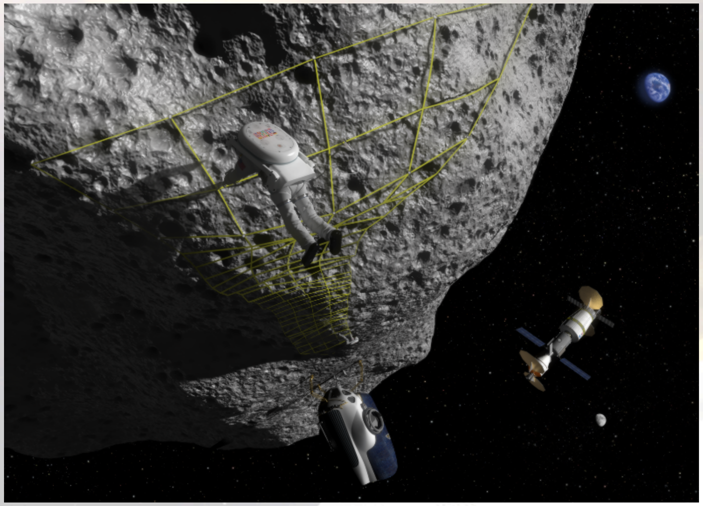
- **The objectives for the robotic mission would be oriented towards data collection to prepare for Human exploration**
  - High-resolution gravity field, density measurements (rubble pile vs. monolith), and topographic mapping
  - Surface composition mapping, resource characterization and distribution
  - Dynamical environment (radiation, dust levitation, plasma fields interactions, etc)

- **The precursor should have some level of direct interaction with the surface (e.g., landers, hoppers, penetrators, etc.)**
  - Near-surface regolith geotechnical properties (composition/size distribution, stability, porosity, compaction, etc.)

- **Robotic sample return prior to the Human mission is not necessary as a risk- or cost-reduction activity**
  - Dust mitigation and contamination protocols can be based on previous small body experience gained from the Hayabusa, Rosetta, Hayabusa 2, and OSIRIS REx missions
  - The Human crew is more suited to obtain macroscopic and diversified samples

# Robotic Precursor Support

- **The precursor may also be extremely valuable during (and after) human mission operations**
  - Experience has shown that small body robotic probes can be operational for 10+ years (e.g., Stardust, Deep Impact, etc.)
  - The precursor can provide situational awareness (bird's eye view) and act as a data/communication relay for any assets out the line of sight
  - It can also act as a data rely for equipment/instruments left behind on the surface for long duration investigations (e.g., geophysical stations, ISRU operations, etc.)



Source: NASA/AMA, Inc.

# Science Enabled by Human Presence

- **Humans are able to perform complex tasks and make rapid decisions in real time**
  - Ideally suited to performing detailed and complex tasks which will be required in low-gravity environmental conditions at planetary surfaces
  - Enables a more efficient and higher quality science return
  - Recognizing and collecting scientifically valuable samples for return to Earth is one of the most important tasks at a small body (e.g., age dating, evolution, parent body processes, etc.)

- **The support infrastructure will further enhance science return**
  - Combination of teleoperated and autonomous systems furthers the capabilities of human interaction and investigation at the target
    - Independent and simultaneous operations
    - Detailed coordinated activities
  - Computer capabilities and power of spacecraft systems can be utilized on station
    - Radar tomography of small body interiors
    - High bandwidth for data transfer and communication
  - Enhanced cargo capacity for operations and samples
    - Delivery of science and engineering equipment to be used during EVAs
    - Capability for larger return and diversity of samples
    - Options for containment (e.g., cold temperatures)

Source: NASA/AMA, Inc.

# Science Investigations

- **Determine the nature of the small body surface geology and mineralogy**
  - This provides context and sample selection information for the returned samples for which these measurements will be conducted in Earth laboratories
  - Information on bulk composition and origin of materials (meteorite affinities/parent bodies)
  - Recognition of any alteration processes (fresh vs. weathered)
  - Can be done via hand held remote sensing or in situ instruments

- **Characterize the regolith of the small body at local and global scales**
  - Interpret the processes that have formed and modified it
  - Study the nature, structure, and degree of maturation
  - Particle size frequency distributions needed to characterize microgravity geology
  - Understand the geotechnical properties (cohesion, density, porosity, etc.)
  - Characterize the thermal inertia and mobility response
  - Best suited to geophysical equipment, subsurface excavation (trenching/drilling/core), probes, etc.

- **Identify and characterize the presence and distribution of volatiles or organics**
  - Investigate at surface, near-surface, and at depth
  - Can be done with hand held remote sensing or in situ instruments
  - Detailed investigation on returned samples relevant for astrobiology

# Science Investigations

- **Determine the near surface and interior structure at regional and global scales**
  - Identification of rubble pile or monolithic structures. Also determination of interior component size frequency distribution (large pieces vs. meter scale bits)
  - Seismic surveys and radar tomography
  - Ground penetrating radar

- **Characterize the dust, plasma, and electrostatics of the airless body**
  - Presence of any exosphere and potential interaction during solar activity
  - Characterize micrometeorite flux (source of dust and any sinks)
  - Combination of in situ probes and spacecraft sensors

- **Measure and monitor radiation environment on site and characterize the response of the small body surface material response**
  - Identify shielding opportunities of small body materials
  - Characterize any secondary radiation emitted from the small body
  - Rad sensors and tissue equivalent detectors

# Future Considerations

- **Opportunities exist for enhanced science capability with the systems and elements needed for missions to the Moon, Mars, and small bodies**
  - Multi-purpose Crew Vehicle (MPCV)
  - Space Launch System (SLS)
  - Exploration Augmentation Module (EAM)
  - Deep Space Habitat (DSH)
  - Multi-Mission Space Exploration Vehicle (MMSEV) (i.e., excursion vehicle)

- **Foster international, commercial, and academic cooperation for both robotic precursor and human missions**
  - JAXA, ESA, Roscomos, CSA, and other exploration agencies
  - Space X, Planetary Resources, Deep Space Industries, Bigelow Aerospace, etc.
  - Scientific and Engineering communities

Source:
NASA/AMA, Inc.